

Office of Aviation Medicine  
Washington, D.C. 20591

# **GPS Design Considerations: Displaying Nearest Airport Information**

Kevin W. Williams  
Civil Aeromedical Institute  
Federal Aviation Administration  
Oklahoma City, OK 73125

April 1998

Final Report

**19980608 181**

This document is available to the public  
through the National Technical Information  
Service, Springfield, Virginia 22161.



U.S. Department  
of Transportation

**Federal Aviation  
Administration**

**DTIC QUALITY INSPECTED 3**

## **NOTICE**

This document is disseminated under the sponsorship of the U.S. Department of Transportation in the interest of information exchange. The United States Government assumes no liability for the contents or use thereof.

**Technical Report Documentation Page**

1. Report No.  DOT/FAA/AM-98/12	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle  GPS Design Considerations: Displaying Nearest Airport Information		5. Report Date  April 1998
7. Author(s)  Williams, K.W.		6. Performing Organization Code
9. Performing Organization Name and Address  FAA Civil Aeromedical Institute P.O. Box 25082 Oklahoma City, OK 73125		8. Performing Organization Report No.
12. Sponsoring Agency name and Address  FAA Office of Aviation Medicine Federal Aviation Administration 800 Independence Avenue, SW. Washington, DC 20591		10. Work Unit No. (TRAIS)
		11. Contract or Grant No.
13. Type of Report and Period Covered		
14. Sponsoring Agency Code		
15. Supplemental Notes		
16. Abstract  Thirty-six participants were tested in a flight simulator on their ability to orient toward the nearest airport, based on the manner in which information was presented on a global positioning system (GPS) display. Results indicated that use of the tabular, text-only format normally found on such displays was significantly slower and less accurate than either a map display of nearest airport information or a text display that included an orientation symbol. In addition, it was found that pilots tended to ignore information available from the heading indicator, and instead, focused solely on the GPS display to perform the task. Discussion of the results includes the need to support pilot decision-making through interface design and the development of design guidelines for GPS displays.		
17. Key Words  Global Positioning System, Human-Computer Interface, Aircraft Displays, Applied Psychology		18. Distribution Statement  Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161
19. Security Classif. (of this report)  Unclassified	20. Security Classif. (of this page)  Unclassified	21. No. of Pages  18
22. Price		

Form DOT F 1700.7 (8-72)

Reproduction of completed page authorized

**DTIC QUALITY INSPECTED 8**

## **ACKNOWLEDGMENTS**

This research is part of the Civil Aeromedical Institute general aviation human factors research program. Program direction is provided by the Aircraft Certification (Small Aircraft Directorate, ACE-100) and General Aviation and Commercial Division (AFS-800) sponsors.

The author expresses his appreciation to Jody Worley, for his help in creating the experimental scenarios and establishing the GPS interface design, and to Howard Harris for his help in recruiting subjects. The author also thanks Dr. Dennis Beringer for his assistance in establishing the experimental protocol.

**Preceding Page Blank**

---

## GPS DESIGN CONSIDERATIONS: DISPLAYING NEAREST AIRPORT INFORMATION

### PURPOSE

This research is part of a multi-task approach to develop and test interventions that will mitigate or eliminate root causes of general aviation (GA) pilot errors and thereby achieve a reduction in general aviation accidents and incidents. The title of the overall research project is "General Aviation: Development and Assessment of Flight Systems Innovations." Human factors information and data gained via this research will provide a sound scientific basis for the Federal Aviation Administration and the GA Industry Coalition to develop and execute certification and rule-making initiatives that will result in gains in general aviation safety.

### INTRODUCTION

Global positioning system (GPS) receivers are being incorporated at a rapid pace into today's general aviation aircraft. While human-interface design standards exist for GPS receivers (FAA, 1995), these standards do not precisely define how information should be presented to the pilot or even what information should be presented. There have been some preliminary studies addressing the human factors aspects of GPS design (Heron, Krolak & Coyle, 1997; Nendick & St. George, 1995; Wreggit & Marsh, *in press*), but many issues remain to be explored. A case in point is the display of nearest airport information. Most GPS units today have a function for displaying the nearest waypoints to the current position of the aircraft. The types of waypoints that can be displayed include very high frequency omnirange (VOR) facilities, nondirectional beacons (NDB), navigation intersections, and airports. The use of the nearest waypoint function for the display of nearest airport information is relevant to pilot safety considerations, since this information could likely be used under emergency and/or distress conditions.

The likelihood of a pilot to make a sound decision while under stress is dependent upon the quality of information available. Two components of pilot decision-making have been identified: cognitive and affective (Brecke, 1981; Driskill, Weismuller, Quebe,

Hand, Dittmar, & Hunter, 1997; Jensen, 1982; Jensen, Adrion, & Lawton, 1987). Driskill et al. define the cognitive component as those processes that are used to establish and evaluate the alternatives in a decision-making situation. Jensen (1982) suggested that the cognitive component relates to the pilot's ability to search for, and establish, the relevance of all available information regarding a situation, to specify alternative courses of actions, and to determine expected outcomes from each alternative. The ability to select between alternative courses of actions is critically dependent on the information available regarding each of those alternatives. The kinds of information available, and the way the information is presented, can alter the decision-making process.

In most current GPS units, nearest airport information is displayed in a text-based format, even if the unit contains a moving-map display. The information usually given to the pilot includes the airport identifier, bearing to the airport, and distance to the airport, for the closest 10 to 20 airports from the current aircraft position. In an emergency situation, a pilot would use the nearest airport function to locate and orient to the nearest airport. While it might be assumed that the pilot would simply select the airport at the top of the list (i.e., the nearest airport in terms of distance), there could exist circumstances where the nearest airport is not the best choice. Consideration of wind, weather, obstacles, traffic, or other factors might influence the selection process. All of these considerations require that the relative direction of each airport from the current aircraft position be known. It is for the benefit of regulators, manufacturers, and end users, that we determine the most effective method of presenting nearest airport information to the pilot so that relative orientation to each airport can be included in the decision-making process.

Since many GPS units have a moving-map display, it is possible to present airport distance and bearing information directly on the moving map, rather than in a text-based tabular format. While there are currently no studies that have directly compared text-based vs. moving map-based presentation of orienting

information, we can hypothesize that a map-based presentation would be superior because a map displays orientation information directly, while orientation must be mentally computed for a text-based display by determining the difference between the airport bearing and the current aircraft heading. The need to integrate information from two separate sources should be more difficult and should take longer than when the information is already integrated, as is found with a map-based presentation.

Despite the expected advantage of a map display over text, there are several reasons for maintaining a text-only display of nearest airport information. First, not all GPS units have a moving-map display. It would be unreasonable to require the added expense of a moving map only for the purpose of displaying nearest airport information, if the advantage gained thereby was minimal. Second, a map display can be more cluttered than a text display, leading to the possibility that some information on the screen is obscured. Finally, there are other reasons for displaying nearest airport information besides an in-flight emergency. For these other tasks, the nearest airport might not be as important as one further away. The nearest airport function allows the user to access information about an airport that might not presently be visible on the map display.

In addition, while there are reasons to suspect that a map display is superior to a text display for providing orienting information, there are reasons to believe that no advantage, or at least a minimal advantage, exists. One reason is that pilots have experience converting a given heading into a generalized compass direction. If the pilot has a clear image of the aircraft's current heading, either by referencing the heading indicator on the instrument panel, or noting the heading from the GPS unit itself, then deciding the relative bearing between the aircraft heading and any given actual bearing should take very little time. A second reason depends on the type of moving-map display used. The two most common types of moving-map displays are the north-up display and a track-up display. In a north-up display, the aircraft symbol rotates to indicate the current heading of the aircraft relative to the top of the map, which indicates north. In a track-up display, the aircraft symbol continuously points straight up, while the map rotates. Thus, the top of the map indicates the current aircraft heading.

The relative benefit of a track-up versus a north-up display is dependent on the type of task being performed (Harwood & Wickens, 1991; Hooper & Coury, 1994; Wickens, 1992). Wickens (1992) hypothesized that a track-up display would be superior to a north-up display for performing an orienting task. Aretz (1991) further hypothesized, and provided empirical evidence to support, the idea that the need to perform a mental rotation (Shepard and Metzler, 1971) caused most of the delay when using a north-up map. Mental rotation will take longer when the aircraft is on a generally south-bound heading than when it is generally north-bound. It is possible that the delays caused by a need to mentally rotate the map image could eliminate the advantage of a map display over the text-based display. This would suggest that only a track-up display would be superior to a text-based display when the aircraft is on a generally south-bound heading.

Interestingly, the earlier discussion regarding the ability of a pilot to convert a given bearing into a direction (i.e., relative to north) presents an intriguing possibility. If the pilot has access to a moving map prior to being presented the text-based orientation information, then orienting should be quicker or more precise if that map was a north-up map than if it was a track-up map. The reason is that, with the north-up map, only a single mental rotation is required to derive orientation information whereas, with a track-up map, the pilot must first mentally rotate the image to derive an absolute heading before mentally rotating the image again to derive orientation information to the airport. For example, given an airport bearing of 155 degrees and an aircraft heading of 45 degrees, orientation to the airport is determined by the angle between 45 and 155 degrees. Using a north-up map, the aircraft symbol is already at the proper angle for making this determination; however, with a track-up map, the aircraft symbol is not in the correct position but must first be mentally rotated to 45 degrees before determining orientation to the airport.

Before imposing a requirement for the graphical presentation of nearest airport information in a GPS display, it would be useful to test whether a measurable advantage is gained. Also, it might be possible to gain the expected advantage of the map display if a symbolic representation of orienting information can be presented as part of the text display. By providing the same amount of information in regards to orientation as

is available in the map display through the use of an orienting arrow, the text display might be as useful as the map display. The text display might actually be superior to a map display that requires mental rotation to compute orientation.

The present experiment was designed to compare various methods for presenting nearest airport information on a pilot's ability to orient quickly and accurately toward the nearest airport. In particular, a question of interest was whether the graphical presentation of that information is superior to a textual presentation and, if so, whether that advantage could be eliminated through the inclusion of an orienting symbol within the text-based display.

Three different methods for presenting nearest airport information were evaluated. The first method represents one that is most commonly found in current GPS receivers and, for this experiment, was called the "text-only" method. In this method, airports are listed, along with the bearing and distance, in a tabular format on the screen. Pilots must decide the relative direction to each airport by comparing their current heading to the listed bearing to the airport. A cross-check of the heading indicator will aid pilots in performing this task, if they remember to reference the heading indicator.

The second method for presenting nearest airport information is within a moving-map display. In this method, the nearest airports are shown directly on the map display, with bearing and distance shown next to the airport.

The third method for presenting nearest airport information is a compromise between the first two and is referred to as the "enhanced-text method." This method is the same as the text-only method, with the exception of an orienting symbol added to each airport listing. This symbol provides a direct indication of the relative direction of the airport, based on the current aircraft heading and bearing to the airport. The symbol was intended to provide the same kind of relative direction information available from the map display, but it is presented in a tabular format.

In addition to these three types of display formats, another question of interest was how the use of a track-up vs. a north-up map display might affect the use of each of the formats. A third variable that was manipulated was the aircraft heading. This variable was included because of prior research that indicated a need for mental rotation that varied as a result of aircraft heading.

The final factor that was manipulated was the subject group. One question of interest was whether aircraft experience would have an effect on the ability to orient under various conditions. A second question was whether the presence and use of a heading indicator during a trial would effect the ability to orient. To answer both of these questions, three groups of participants were used in the study. The first group of participants was comprised of non-pilots, having no flight experience. During the experiment, participants in this group interacted only with the GPS unit and were not required to fly the simulator. A second group of participants consisted of pilots holding at least a private pilot certificate but like the first group, interacting only with the GPS display. The final group of participants included pilots holding at least a private pilot certificate, and in addition to interacting with the GPS display, also flew a flight simulator during performance of the orientation task. The simulator provided the pilot access to a heading indicator that could be used to aid in orientation decisions.

## METHODS

### Participants

Thirty-six participants were recruited from the Oklahoma City metroplex area. Twenty-four of the participants held current private pilot certificates. The other 12 participants were non-pilots. Pilots were recruited from local fixed-base operations (FBOs). Non-pilots were recruited through Acheson Consulting, Incorporated, a firm contracted by the FAA to provide experiment participants for Civil Aeromedical Institute research projects. All participants were paid. Information was collected regarding participant's education level, gender, flight experience, age, handedness, and GPS experience. Among the pilot participants, only one was female. Among the non-pilots, four were female. Flight experience among the two pilot groups was similar (860 average flight hours for the non-simulator group, 757 average flight hours for the simulator group). GPS use among the two pilot groups was also similar with 6 of 12 from the non-simulator group reporting having used a GPS and 7 of 12 from the simulator group reporting having had experience with a GPS unit. None of the non-pilots had ever used a GPS display.

## Facilities

Data collection was performed using the Basic General Aviation Research Simulator (BGARS) located at the FAA Civil Aeromedical Institute in Oklahoma City. BGARS is a medium-fidelity, fixed-base, computer-controlled flight simulator. The controls and displays used in the BGARS for this study simulate those of a Beech Sundowner. Control inputs are provided by high-fidelity, analog controls, including a damped and self-centering yoke, navigation radio frequency selection module, rudder pedals, throttle, gear, flap, and trim controls. Instruments are displayed on a CRT and react in real time to control inputs and aircraft conditions. The external views consist of a 50-degree forward-projected view, two smaller right-side-view CRTs, and two smaller left-side-view CRTs. A GPS display was hosted on a 10-inch, True Point, touch-screen panel located just to the right of the pilot position and within easy reach of the pilot. Participants interacted with the panel using only their right hand. One group of 12 participants operated the simulator while interacting with the GPS display. The other two groups of participants sat in the pilot position while interacting with the GPS, but they did not operate the simulator.

## Experimental Design

Four factors were manipulated in the experiment: 1) Participant type (pilot/no sim, pilot/sim, and non-pilot); 2) nearest airport information display mode (text-only display, enhanced-text display, map display); 3) map display mode (north-up or track-up); and 4) aircraft heading (generally north or generally south), resulting in a 3x3x2x2 experimental design. Participant type was a between-subjects condition, while the other three conditions were within-subjects. Dependent variables that were collected included orientation response time, orientation response accuracy, number of additional training trials required for each condition, and score on a verbal test of spatial abilities (Ackerman & Kanfer, 1993).

## Design of Trials

Four aircraft headings were used in the experimental trials. Two headings were for the generally north condition (345 degrees and 015 degrees), and the other two headings were used in the generally south condition (165 degrees and 195 degrees). In addition, four pairs of airports were selected from a navigational chart of the Oklahoma area for use in the experiment.

Two of the airport pairs were located east and west of each other, the other two pairs were located north and south of each other. Each airport was approximately 20 miles from its pair. No airport was located close to a large metropolitan area.

For each airport pair, for each aircraft heading, four aircraft positions were selected that met the following conditions: 1) the position was approximately half-way between both airports, but definitely closer to one airport than the other; and 2) the direction to the closest airport corresponded to one of four clock directions relative to the aircraft consisting of either the 1, 4, 7 or 10 o'clock positions or the 2, 5, 8 or 11 o'clock positions. For two of the airport pairs, the clock directions were 1, 4, 7 and 10 o'clock, for the other two pairs, the clock directions were 2, 5, 8 and 11 o'clock. The total number of positions selected was 4 (airport pairs) x 4 (headings) x 4 (clock positions) = 64 positions. From these 64 positions, 48 were selected at random for each subject to be used as experimental trials. The positions were selected randomly with the constraints that half were north and half were south aircraft headings, and for half of the north and south trials the relative direction of the nearest airport was in front of the aircraft (the 1, 2, 10, or 11 o'clock positions) and for the other half the relative direction of the nearest airport was behind the aircraft (the 4, 5, 7 or 8 o'clock positions).

Half of the 48 experimental trials were used for actual data collection, the other half were used for participant practice. During the experiment, participants were exposed to 24 actual trials, representing two repetitions of each of the 12 possible within-subject conditions. The number of practice trials the participant was exposed to depended on performance, with the minimum number of practice trials set at 36, so that some of the practice trials were used more than once for each participant.

## Procedure

Participants were tested individually. The participant received a consent form to read and sign and then completed an experience questionnaire. Questions gauged the participant's age, gender, handedness, educational level, flight experience, and GPS experience. Following completion of the questionnaire, the participant performed a verbal test of spatial abilities (see Ackerman & Kanfer, 1993). After completing this test, the participant was seated at the simulator, and an explanation of the experimental task was presented. During the actual

experiment, presentation of trials was grouped by presentation mode (text, map, enhanced-text) within map mode (track-up, north-up). Participants received a minimum of ten practice trials on a particular presentation mode and then were given four actual trials for that mode. Within each set of four actual trials, the order of northbound and southbound trials was random. During the practice trials, participants were first presented with at least five trials under a northbound condition and then at least five trials for the southbound condition. The number of practice trials for a particular mode was extended if the sum of the orientation error over the last two trials exceeded 160 degrees, indicating the participant was confused regarding the task procedure.

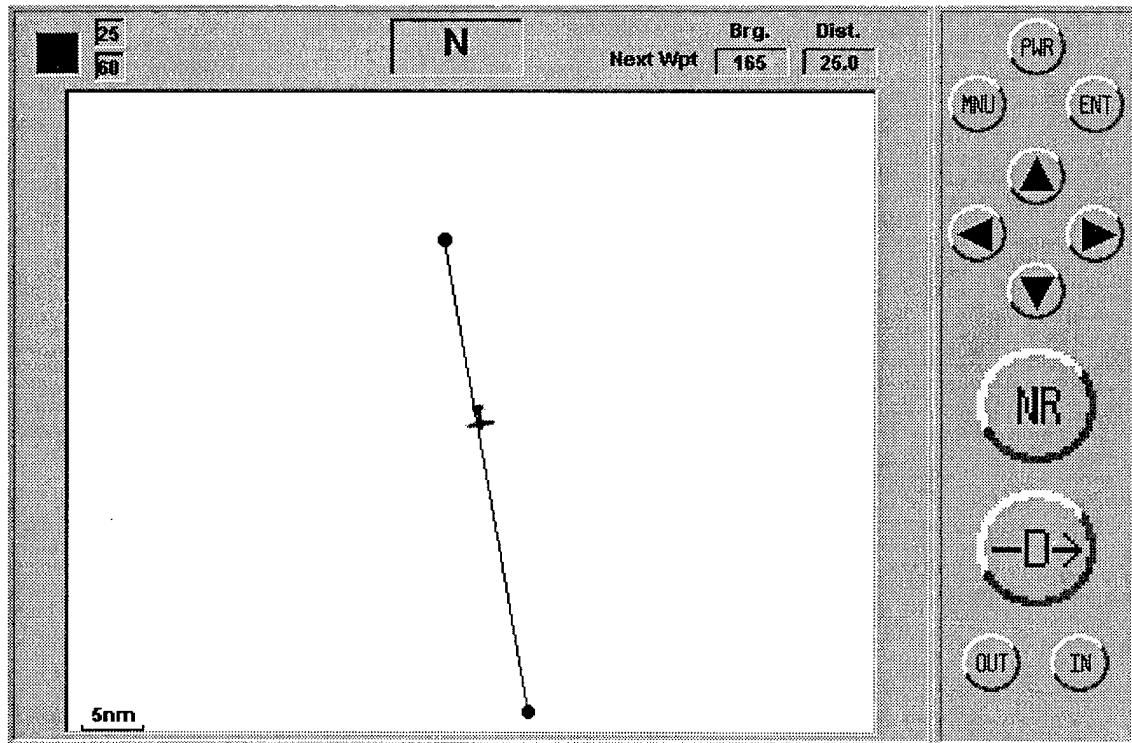
After completing the four actual trials for a particular presentation mode, the participant was given practice and actual trials for the next presentation mode. After all modes had been completed under a particular map mode condition, the map mode was changed (from track-up to north-up or vice versa), and practice and actual trials were given for each presentation mode as described above, with the exception that only two practice trials were given for each mode, unless the orientation error on the last practice trial exceeded 80 degrees. In all, a minimum of 36 practice trials were completed, along

with 24 actual trials. The order that participants received presentation and map mode conditions was counterbalanced.

Following completion of the experimental task, participants were debriefed and asked which of the experimental conditions they preferred the most. Their preferences were recorded and they were then dismissed.

### Orientation Task

Figure 1 shows an example of the GPS display (north-up map mode) at the beginning of each trial. Under the track-up map mode, the airplane symbol pointed straight up and the current aircraft heading was shown in the center box above the moving-map display (in place of the large "N"). Participants flying the simulator were asked to maintain the course shown on the display. No airports were shown on the moving-map display until after the nearest airport function had been activated to prevent participants from beginning the orientation task early. The actual orientation task began when a large red "EMERGENCY" message appeared just above the airplane symbol, accompanied by a steady beeping from the computer speaker which was the indication for the participant to begin the orientation task.



**Figure 1.** Example GPS display at the beginning of each trial (north-up map mode)

Participants were asked to perform a five-step orientation procedure. The first step was to note the current aircraft heading. The second step was to press the "NR" button on the display to bring up the nearest airport information. Based on the information presented in the display, the third step was to decide the relative direction of the nearest airport in the form of clock position. That is, participants had to decide the clock position that corresponded to the direction to the nearest airport, with 12 o'clock being directly in front of the aircraft and 6 o'clock directly behind the aircraft. The fourth step was to press the direct-to button (i.e., the button with the D with an arrow through it) on the GPS display to bring up the screen shown in Figure 2. The final step was to press the point on the large black circle corresponding to the appropriate clock position of the nearest airport (see Figure 2). After the large circle was pressed, the trial ended, and the next trial was immediately begun.

Nearest airport information was presented in one of three ways. The first method, shown in Figure 3, was called the text-only method. In this method, the nearest airports were listed in a tabular format on the screen with the airport identifier, bearing to the air-

port, and distance to the airport shown. An asterisk was positioned next to the closest airport for easy identification. In the example shown in Figure 3, the aircraft is on a heading of 165 degrees. The nearest airport, OK09, is at a bearing of 212 degrees, or approximately between the 1 and 2 o'clock position (47 degrees to the right) from the aircraft heading. The participant, after deciding the relative direction of the nearest airport, would press the direct-to button to bring up the display shown in Figure 2, and would then press approximately the 1:30 position on the circle to indicate the relative direction of the nearest airport.

The second method for presenting nearest airport information is shown in Figure 4. Known as the enhanced-text method, this method is similar to the text-only method with the exception of an additional symbol located to the right of the airport information. This symbol is an indication of the relative direction to each of the airports listed. In the example shown in Figure 4, the aircraft is on a heading of 015 degrees. Airport 3F7 is at a bearing of 135 degrees. The orientation symbol on the right indicates that to fly toward airport 3F7, the pilot needs to turn 120 degrees to the right, or to the 4 o'clock position. As

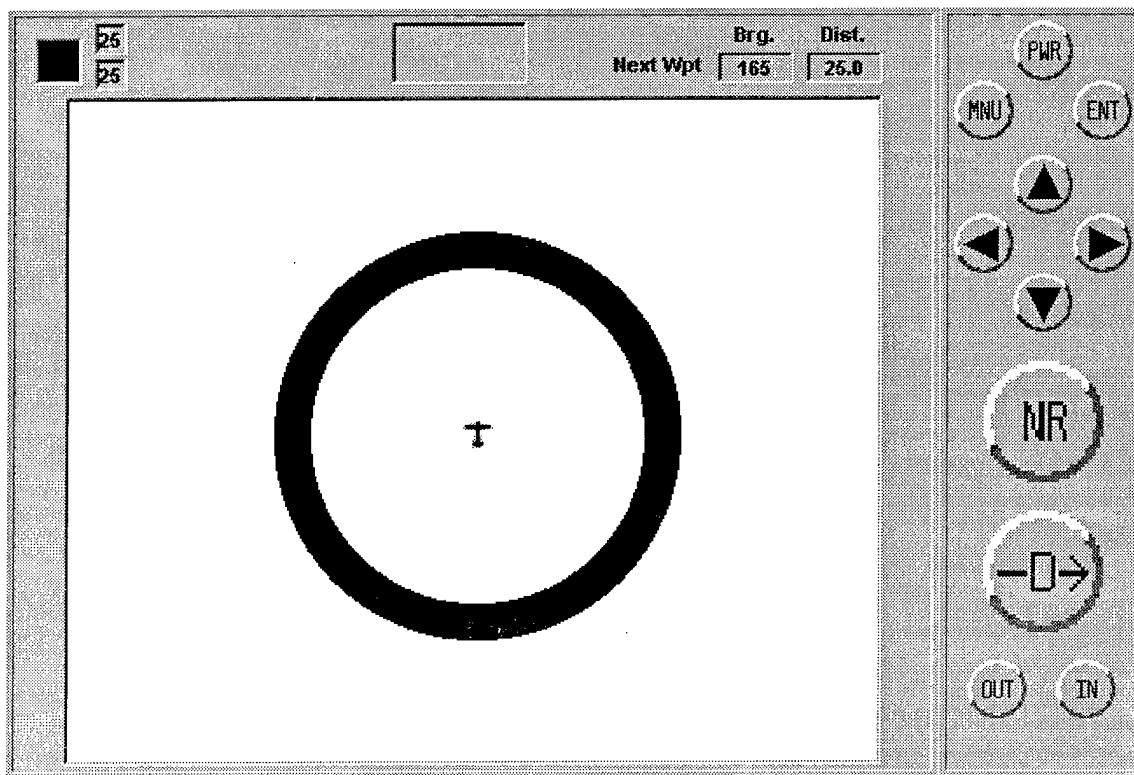


Figure 2. GPS display after pressing the direct-to button

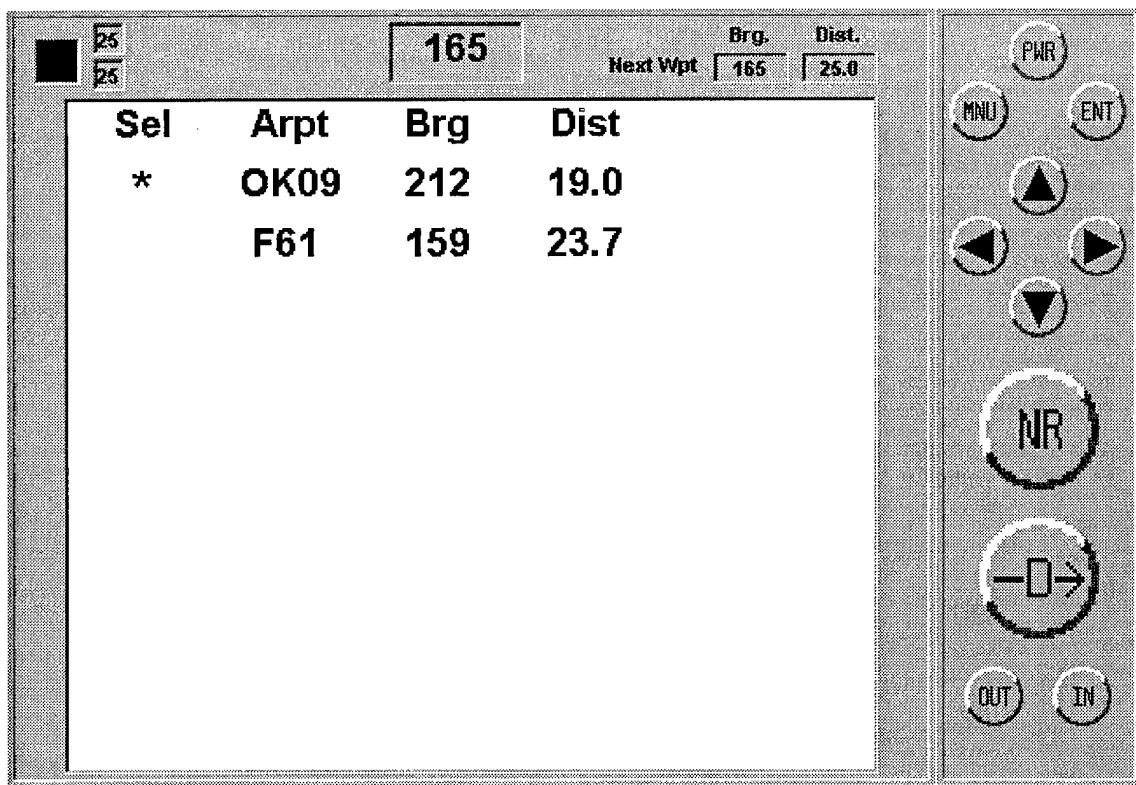


Figure 3. Text-only method of presenting nearest airport information

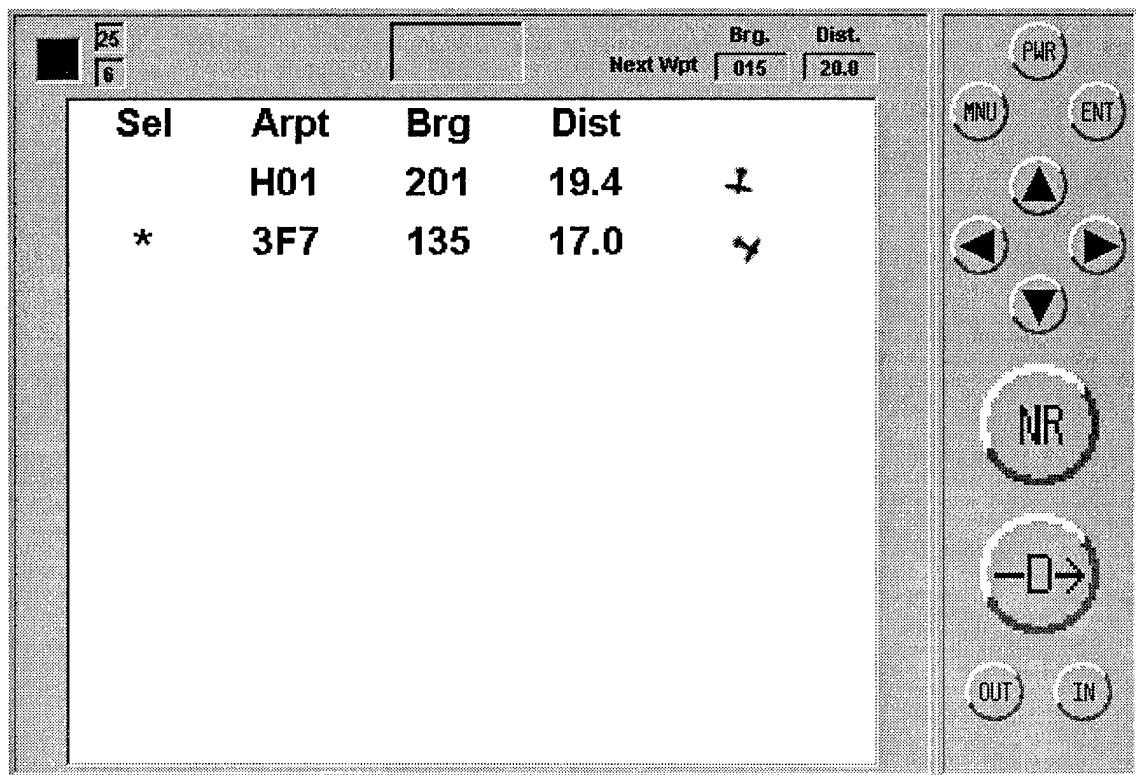


Figure 4. Enhanced-text method for presenting nearest airport information

with the text-only method, the asterisk indicates the nearest airport. Again, the participant would press the direct-to button and then press the 4 o'clock position on the circle.

The third method for presenting nearest airport information is shown in Figure 5. In this method, the nearest airports are shown in a map display, with an asterisk positioned next to the closest airport. In the example shown, the aircraft is on a heading of 165 degrees. The nearest airport, OK09, is at a bearing of 240 degrees, or 75 degrees to the right of the current aircraft heading. This corresponds to a position between 2 and 3 o'clock from the current aircraft heading.

For each of the trials, two types of data were collected. One was the difference between the actual relative direction to the nearest airport (i.e., the o'clock position) and the indicated relative direction to the nearest airport, measured in degrees. The other was the response time for indicating relative direction, measured in milliseconds from the time that the nearest airport information was first presented on the display. In addition, the number of practice trials

required for each of the combinations of presentation mode (text-only, enhanced-text, map) and map mode (track-up, north-up) was recorded.

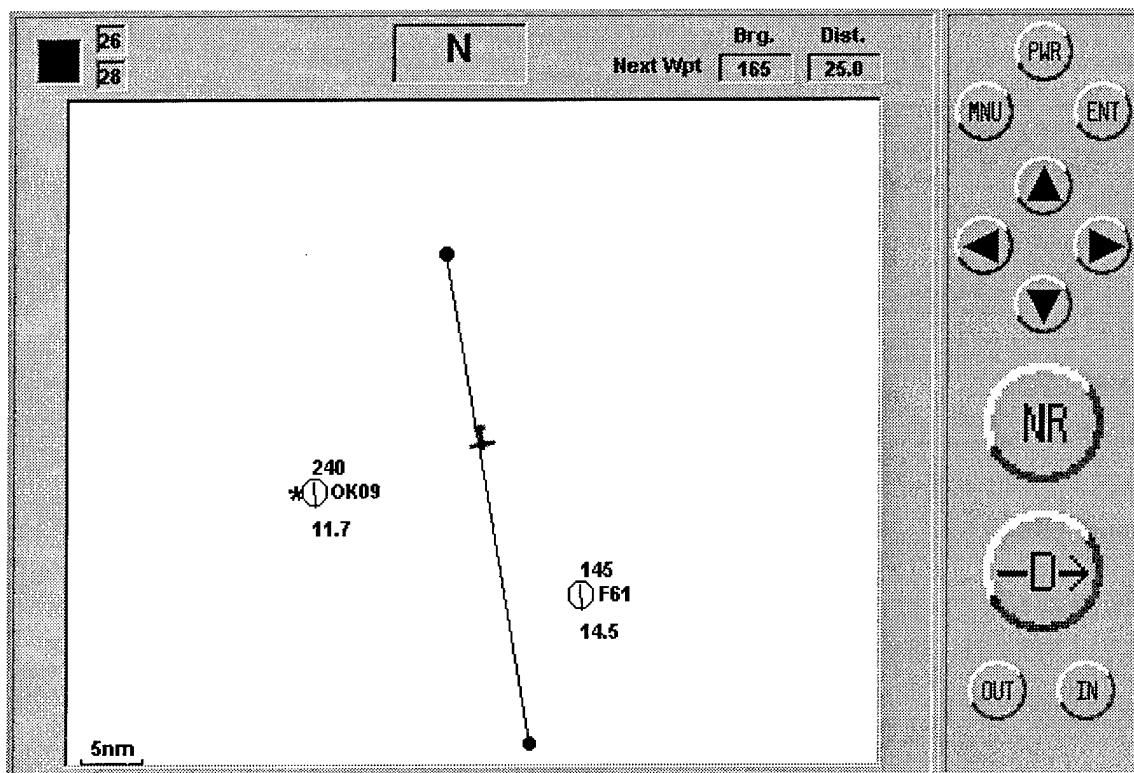
## RESULTS

### Verbal Test of Spatial Abilities

An analysis of the spatial abilities test scores did not reveal any differences in spatial abilities among any of the participant groups. In addition, when the spatial abilities test score was used as a covariate for the analysis of variance measures, it had no effect on the results. Therefore, the spatial abilities test was dropped from the analyses and will not be discussed.

### Misorientation Errors

Instead of a direct analysis of the difference between the actual airport orientation and indicated airport orientation for each trial, the concept of a misorientation error was created. A misorientation error was defined as an error of more than 45 degrees in judging the relative direction of the nearest airport.



**Figure 5.** Map method for presenting nearest airport information (north-up mode)

The purpose of this definition was to eliminate error caused by an unsteady hand or by imprecision in the touch-screen panel. This allowed us to focus on those errors that were actually due to misjudging the relative direction to the nearest airport. A 3x3x2 analysis of variance was performed on the number of misorientation errors committed by participants under each experimental condition.

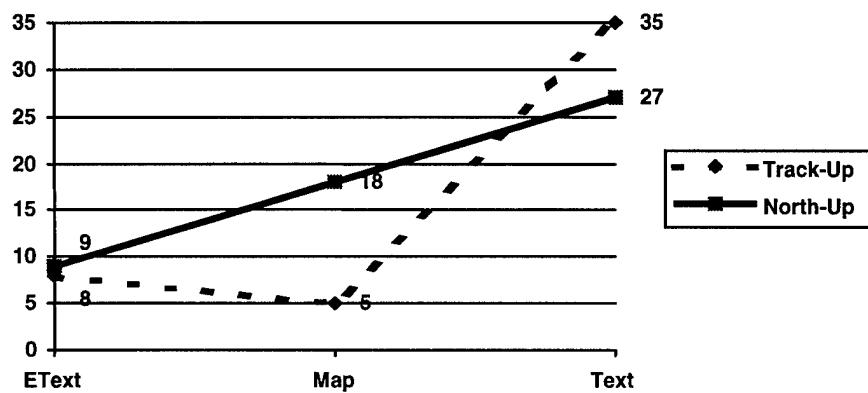
For all of the analyses reported in this paper, no significant 3-way or 4-way interactions were found, so for the sake of brevity, these will not be discussed. Table 1 gives a count of the number of misorientation errors for each experimental condition, with the exception that we have collapsed across aircraft heading, since none of the significant effects involved this factor. Looking at the results of the analysis, the 2-way presentation mode x map mode interaction was significant,  $F(2, 66) = 3.913, p = 0.025$ . Also, two main effects were significant. The effect due to presentation mode was significant,  $F(2, 66) = 13.258, p < 0.001$ , as was the between subjects effect of participant type,  $F(2, 33) = 6.212, p = 0.005$ .

From Table 1, it is clear that the significant effect of participant type was because non-pilots made significantly more errors than either of the pilot groups (55 errors for the non-pilots vs. 20 and 27 errors for each of the pilot groups). This was true under all presentation modes but particularly for the text-only condition. The text-only condition was clearly the most difficult, with more than half of all of the errors (62 of 102) made under this presentation mode. Additionally, even if the non-pilots are eliminated from consideration, more errors were made by pilots in the text-only condition than in both of the other conditions combined (28 vs. 19 errors respectively).

Figure 6 shows the interaction between presentation mode and map mode on the number of misorientation errors. Note that the numbers used in the figure are total misorientation errors across all participants and not the number of errors per participant that was used in the actual analysis of variance. The reason for the change is that these numbers are easier to understand and display the same profile as the errors per participant numbers. As can be seen

**Table 1.** Misorientation error totals

Map Mode	Presentation Mode	Participant Type			Total
		Pilots/NoSim	Pilots/Sim	Non-Pilots	
North-Up	EText	1	3	5	9
	Map	3	5	10	18
	Text-Only	5	6	16	27
Total		9	14	31	54
Track-Up	EText	3	2	3	8
	Map	0	2	3	5
	Text-Only	8	9	18	35
Total		11	13	24	48



**Figure 6.** Number of misorientation errors as a function of presentation mode and map mode.

from Figure 6, the significant interaction effect is due primarily to there being more errors using the north-up map for the map presentation condition, but more errors using the track-up map when nearest airport information was presented in the text-only format. This last finding seems to support the hypothesis stated earlier that an additional mental rotation is required in the text-only condition when referencing a track-up map. Map mode did not seem to have an effect on the probability of making an error under the enhanced-text condition.

### Response Time

A  $3 \times 3 \times 2 \times 2$  analysis of variance was performed on the response time between presentation of nearest airport information until the relative direction to the nearest airport was indicated by touching the appropriate point on a circle drawn on the touch-screen panel (see Figure 2). Response time was measured in milliseconds.

Table 2 shows the mean response time for each experimental condition, again with the exception that we have collapsed across aircraft heading since none of the significant effects involved this factor. Analysis of these factors yielded significant effects due to map mode,  $F(1, 33) = 7.468$ ,  $p = 0.01$ , and presentation mode,  $F(2, 66) = 42.922$ ,  $p < 0.001$ , as well as the 2-way presentation mode  $\times$  map mode interaction,  $F(2, 66) = 4.982$ ,  $p = 0.01$ . No other main effects or interactions were significant.

Looking at Table 2, we see that participants performed significantly slower while using the north-up map mode than when using the track-up map mode (7525 and 6811 milliseconds respectively). Unlike the commitment of errors, non-pilots did not significantly differ from the pilots in their response times.

Participants were nearly twice as slow at interpreting the text-only presentation of nearest airport information than they were interpreting either the enhanced-text or map presentations (10573, 5451, and 5481 milliseconds respectively).

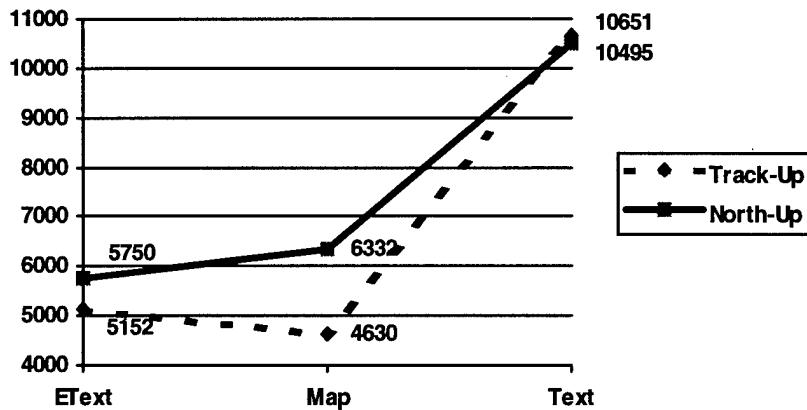
Figure 7 shows the interaction between presentation mode and map mode on response time. As can be seen from Figure 7, the significant interaction effect is due primarily to slower response times using the north-up map for the map presentation and enhanced-text conditions, but not for the text-only condition. As could be expected, the largest difference in response time was found for the map condition. While the difference was not significant, the slightly longer response times for the enhanced-text condition while using the north-up map could be attributed to some confusion regarding how to interpret the orientation symbol. Some of the participants suggested after completion of the experiment that they were confused about whether the orientation symbol was relative to north or relative to the current aircraft heading. This confusion seemed more likely after being exposed to a north-up map.

### Practice Trials

One final analysis was performed on the number of additional practice trials required for each of the experimental conditions. According to the experimental paradigm, participants received a minimum number of practice trials for each of the experimental conditions. Additional trials were administered if a predetermined level of performance had not been achieved. A  $3 \times 3 \times 2 \times 2$  analysis of variance was performed on the number of additional practice trials required for each condition.

**Table 2.** Response time averages (in milliseconds)

Map Mode	Presentation Mode	Participant Type			Mean
		Pilots/NoSim	Pilots/Sim	Non-Pilots	
North-Up	EText	7542	5344	4365	5750
	Map	6823	6338	5835	6332
	Text-Only	10579	9898	11007	10495
Mean		8314	7193	7069	7525
Track-Up	EText	7067	4301	4088	5152
	Map	4429	4427	5034	4630
	Text-Only	10077	10159	11718	10651
Mean		7191	6296	6946	6811



**Figure 7.** Response time as a function of presentation mode and map mode

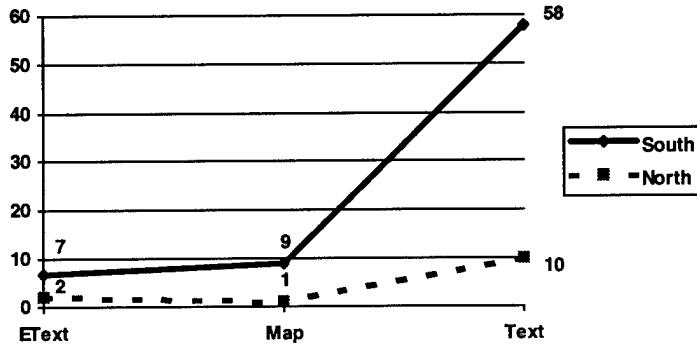
**Table 3.** Additional practice trials

Map Mode	Aircraft Heading	Presentation Mode			Total
		Etext	Map	Text-only	
Track-Up	North	1	1	1	3
	South	1	2	15	18
	Total	2	3	16	21
North-Up	North	1	0	9	10
	South	6	7	43	56
	Total	7	7	52	66

Table 3 shows the total additional practice trials for each experimental condition, with the exception that we have collapsed across participant type, since none of the significant effects involved this factor. Looking at the results of the analysis, the main effects due to map mode,  $F(1, 33) = 4.341, p = 0.045$ , presentation mode,  $F(2, 66) = 8.18, p = 0.001$ , and aircraft heading,  $F(1, 33) = 9.851, p = 0.004$ , were all significant. In addition, the 2-way presentation mode x aircraft heading interaction was significant,  $F(2, 66) = 3.612, p = 0.032$ . No other main effects or interactions were significant.

From Table 3, we see that significantly more additional practice was required for the text-only condition than for the other two conditions and that more practice trials were required for the north-up map mode than for the track-up map mode (66 vs. 21 additional trials respectively). Finally, significantly more practice trials were required when the aircraft

was on a generally south heading than when it was traveling generally north. While most of the additional practice occurred for the text-only condition, one interesting note is the increased number of practice trials for both the enhanced-text and map conditions when the map mode was north-up and the aircraft heading was generally south. For both presentation modes, the data suggests confusion about the correspondence between the aircraft symbol heading and the airplane heading. In the case of the map-mode condition, participants would forget to mentally rotate the image to the appropriate orientation. In the case of the enhanced-text condition, participants were sometimes confused about whether the orientation symbol was relative to north or relative to the current airplane heading. The existence of this confusion was substantiated both by post-experimental questioning of the participants and by remarks made during practice.



**Figure 8.** Additional practice trials as a function of presentation mode and aircraft heading

Figure 8 shows the interaction between presentation mode and aircraft heading on additional practice trials. As can be seen from the figure, the significant interaction effect is attributable to the large difference in practice trials between northbound and southbound conditions for the text-only presentation relative to the other two presentation conditions. This large difference was due primarily to confusion as to how to compute relative direction to the airport based on heading and bearing to the airport. Even if the participant did not quite grasp the experimental task, performance was still adequate in the northbound conditions because relative and absolute directions were nearly identical. However, this was not so when the airplane was southbound. In the southbound condition, an understanding of task requirements was essential to completing the practice trials.

## DISCUSSION

Taken as a whole, these results make a strong argument against use of a text-only, tabular display of nearest airport information. Approximately three times as many misorientation errors occurred using the text-only display than with either of the other two display conditions (62 for text-only, 23 for map, 17 for enhanced-text). In addition, participants, on average, were twice as slow using the text-only display than with either of the other two display methods — a full 5 seconds slower on average. Finally, most of the additional practice trials occurred under the text-only condition. One interesting note was the lack of a difference in speed or accuracy under the text-only condition between pilots using the simulator and pilots not using the simulator. This suggests that even when a heading indicator was available, pilots did not

use it for deciding relative direction. Post-experimental questioning confirmed that most of the pilots did not make use of the heading indicator for deciding relative direction. A failure to cross-reference the GPS display with the other available instruments could simply be a result of the laboratory setting; however, it could also indicate that pilots tend to become fixated on the GPS display and fail to scan properly, a tendency noted in an earlier study of GPS use (Wreggit & Marsh, 1996).

A second important finding was that participants using a north-up display were three times as likely to commit a misorientation error as participants using a track-up display. Among only the pilots, four times as many errors were committed using a north-up display as the track-up display (eight vs. two respectively). In addition, participants were significantly slower using the north-up display than the track-up display (6332 msec. vs. 4629 msec., on average). Finally, four times as many practice trials were required with the north-up display than with the track-up display. While all of this is strong support for the use of track-up displays over north-up displays, there could be situations where a world-referenced coordinate system (i.e., north-up display) would be more beneficial to the decision-making process than an egocentric system (such as is found with a track-up display). The decision as to which map display is the most effective could depend on what kinds of information are being integrated with the display.

Finally, the use of an enhanced-text display, while clearly superior to a text-only display, did not appear quite as effective as the map display. Though there was not a significant difference between the enhanced-text and map displays, there was a tendency for confusion over whether the symbol was north-referenced or

track-referenced (it was, in fact, track-referenced). This confusion sometimes caused a delay in processing while the symbol was cross-referenced with the bearing and heading information. It is possible that a small amount of training could eliminate any confusion regarding the symbol, but this hypothesis remains to be tested.

While it is true that the current research was intended to address a specific design feature found in current GPS units, the results could be extended to any generic aircraft navigational display. In determining the ramifications of any research, it is important to view the experimental results from a common set of assumptions. One primary assumption made in the current research is that the GPS nearest airport function will be used to present a set of alternative airports, possibly under emergency conditions, and that pilots will select from among the alternatives what they hope is the best (i.e., closest, safest route, etc.). For most GPS units currently on the market, assistance regarding orientation to a specific airport, except for bearing information, is given only after that airport has been selected and, therefore, after information about any other alternative has been removed. However, there are several reasons that airport orientation should be considered as one of the factors involved in the airport selection process. The presence of obstacles or the lack of suitable terrain for making an emergency landing could mean that flying toward one airport is not as safe as flying toward a different airport that is only slightly more distant. In addition, the presence of even a moderately strong wind could greatly alter the time it takes to reach an airport that is in the same direction as the prevailing wind, as opposed to one that lies in the opposite direction. Recent research by Weigmann and Shappell (1997) showed that errors in judgment were more frequently associated with more serious airplane accidents, while procedural errors were more frequently associated with minor airplane accidents. This finding leads us to suggest that we need to give stronger consideration to the information available for making in-flight judgments, of which airport selection during an emergency is certainly an example.

Given that airport orientation should be included as a part of the decision regarding which of two or more airports to select, it is clear from the present study that the use of a text-only tabular display, which provides only bearing and distance to the airport, is inferior. However, this still begs the question of which display is the best. For an analysis of this question, we

must turn to the problem of aeronautical decision-making that was touched on in the introduction. Recall that Jensen (1982) posited a cognitive component to aeronautical decision-making that relates to the pilot's ability to search for and establish the relevance of all available information regarding a situation, to specify alternative courses of actions, and to determine expected outcomes from each alternative.

When we consider the types and amount of information presented on a GPS display, we must consider the tradeoff between the benefit of a more effective decision and the amount of time and resources required to make that decision. By providing more information regarding a set of options we allow for a better decision-making process to occur. However, if the time and resources expended by including this information in the decision delays the time to make the decision, or causes other relevant and more important information to be missed, then the tradeoff is negative. Kleinmuntz and Schkade (1993) stated that decision makers engage in a form of cognitive cost-benefit analysis. Displays influence the anticipated effort and accuracy of the decision-making process, and, therefore, influence the strategy adopted in making the decision. Recently, Hendy, Liao, and Milgram (1997) stated much the same idea when they said, "Humans adapt to excessive processing load by changing their processing strategy so as to reduce the amount of information to be processed or to increase the time available before an action has to be performed." (p. 32). Applying this concept to the present research, it is likely that a text-only display of nearest airport information encourages the pilot to adopt a decision-making strategy that does not include the comparison of information from two or more alternative airports. A likely reason for this is that the time and effort required to include this information is judged to be not worth the anticipated benefit.

By making it easier to compare the positions of several airports, we influence the anticipated effort of the task, and thereby increase the likelihood that this position information will be included in the decision of which airport to select. However, at the same time, we need to influence the anticipated benefit of the added information. Two ways this can occur is through training or experience. If a training program were established to demonstrate the utility of considering airport orientation, it might prevent a pilot from learning the lesson through experience. In aviation, there are many lessons that are best left to training.

## REFERENCES

Ackerman, P.L. & Kanfer, R. (1993). Integrating laboratory and field study for improving selection: Development of a battery for predicting air traffic controller success. *Journal of Applied Psychology*, 78(3), 413-32.

Aretz, A.J. (1991). The design of electronic map displays. *Human Factors*, 33(1), 85-101.

Brecke, P. (1981). Instructional design for aircrew judgment training. *Proceedings of the First Aviation Psychology Symposium*. Columbus, OH: The Ohio State University, 145-60.

Driskill, W.E., Weissmuller, J.J., Quebe, J., Hand, D.K., Dittmar, M.J., & Hunter, D.R. (1997). *The use of weather information in aeronautical decision-making*. U.S. Department of Transportation, Federal Aviation Administration, Office of Aviation Medicine, Washington, D.C. NTIS # DOT/FAA/AM-97/3.

FAA (1995). *FAA aircraft certification human factors and operations checklist for standalone GPS receivers (TSO C129 Class A)*. DOT/FAA/AAR-95/3. U.S. Department of Transportation, Federal Aviation Administration, Washington, D.C.

Harwood, K. & Wickens, C. (1991). Frames of reference for helicopter electronic maps: The relevance of spatial cognition and componential analysis. *International Journal of Aviation Psychology*, 1(1), 5-23.

Hendy, K.C., Liao, J., & Milgram, P. (1997). Combining time and intensity effects in assessing operator information-processing load. *Human Factors*, 39(1), 30-47.

Heron, R.M., Krolak, W. & Coyle, S. (1997). A human factors approach to use of GPS receivers. Heron Ergonomics, Inc. Downloaded from Internet, URL <http://bluecoat.eurocontrol.fr/reports/>.

Hooper, E.Y. & Coury, B.G. (1994). Graphical displays for orientation information. *Human Factors*, 36(1), 62-78.

Jensen, R.S. (1982). Pilot judgment: Training and evaluation. *Human Factors*, 24, 61-73.

Jensen, R.S., Adriion, J., & Lawton, R.S. (1987). *Aeronautical decision making for instrument pilots*. U.S. Department of Transportation, Federal Aviation Administration, Office of Aviation Medicine, Washington, D.C. NTIS # DOT/FAA/PM-86/43.

Kleinmuntz, D.N. & Schkade, D.A. (1993). Information displays and decision processes. *Psychological Science*, 4(4), 221-7.

Nendick, M.D. & St. George, R. (1995). Human factors aspects of global positioning systems (GPS) equipment: A study with New Zealand pilots. *Proceedings of the Eighth International Symposium on Aviation Psychology*. Columbus, OH: The Ohio State University, 152-7.

Shepard, R.N. & Metzler, J. (1971). Mental rotation of three-dimensional objects. *Science*, 171, 701-3.

Weigmann, D.A. & Shappell, S.A. (1997). Human factors analysis of postaccident data: Applying theoretical taxonomies of human error. *International Journal of Aviation Psychology*, 7(1), 67-81.

Wickens, C. (1992). *Engineering Psychology and Human Performance* (2<sup>nd</sup> ed.). NY: Harper Collins.

Wreggit, S.S. & Marsh, D.K. (in press). *Cockpit integration of GPS: Initial assessment — menu formats and procedures*. U.S. Department of Transportation, Federal Aviation Administration, Office of Aviation Medicine.